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Factors influencing the conservation characteristics of baled and precision-chop grass silages

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The composition of baled silage on Irish farms frequently differs from that of comparable precision-chop silage. This paper concerns a field-scale study designed to investigate: (a) the effects of number of layers (2, 4, 6 or 8) of polyethylene stretch film and the duration of storage (7 *vs.* 18 months) on the conservation characteristics of baled silage, and (b) the conservation characteristics of baled (4 layers of stretch film) and precision-chop silages. All silages were made following three durations of wilting (0, 24 or 48 h). Wilting restricted silage fermentation, with silage pH being highest (P<0.001) and the concentration of fermentation products lowest (P<0.001) for the 48 h wilt treatment. Wrapping bales in only 2 layers of polyethylene stretch film resulted in extensive visible mould growth, but mould growth was practically eliminated by the application of 4 or more layers of film. Silage fermentation characteristics were generally improved by wilting, and by 4 compared to 2 layers of stretch film. Extending the storage duration of baled silage from 7 to 18 months reduced (P<0.001) the concentration of fermentation products and increased in-silo fresh weight losses (P<0.001) and visible mould growth. Whereas 4 layers of conventional stretch film are normally sufficient, 6 layers may be necessary to prevent mould growth when bales of unwilted silage are stored for a second season. Under good farm-management conditions differences observed between baled and precision-chop silages probably result mainly from differences in the concentration of dry matter in herbage at ensiling.

Keywords: baled silage; fermentation; grass silage; precision-chop silage

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Introduction

Grass silage is the next most important ruminant feedstuff in Ireland after grazed grass. Two main silage harvesting systems are employed: precision-chop silage stored in horizontal silos (0.60 of national silage area) and individual bales of silage wrapped in polyethylene stretch film (0.32 of national silage area; O'Kiely *et al*. 2000). Although the principles controlling conservation and nutritive value should be the same for both systems, the composition of baled silage frequently differs from that of precision-chop silage (i.e., higher dry matter concentration, higher pH and lower concentration of fermentation products) (Fychan, Fraser and Jones 2002; McEniry *et al*. 2006, 2008). Furthermore, the challenge from undesirable microorganisms, such as moulds, can be relatively high with baled silage (O'Brien *et al*. 2005).

Among the factors within the baled-silage system that could potentially explain the differences in composition from precision-chop silage are the concentration of dry matter (DM) in the herbage, herbage chop length, the extent of herbage compaction and air infiltration during storage. Studies with laboratory silos (McEniry *et al*. 2007) showed that field wilting and air infiltration during ensiling each had a much larger impact on the conservation characteristics of silage than chopping or compaction. Baled silage is regularly made from more extensively wilted herbage compared to herbage for conventional silage (DM *ca.* 360 *vs.* 220 g/kg; McEniry *et al*. 2006) since wilting reduces the number of bales to be wrapped and transported, assists preservation, eliminates effluent output and can result in a more convenient product to handle at feeding time (O'Kiely *et al*. 2000). In general, more extensive wilting results in forages with lower water activity, which in turn creates more inhibitory conditions for microbial fermentation and particularly for the activity of undesirable microorganisms such as *Clostridia* (Woolford 1984).

Anaerobiosis is the main prerequisite for successful ensilage. The infiltration of even small amounts of air can delay plant cell lysis and lead to the creation of conditions that are not conducive to a lactic-acid dominant fermentation (Ruxton, Clark and McDonald 1975). In contrast to precision-chop silage, where the herbage is sealed beneath 2 layers of polythene sheeting (0.125 mm thick), baled silage is mechanically wrapped in nominally (in Ireland) 4 layers of polyethylene stretch film giving an average barrier thickness of approximately 0.07 mm. Thus, baled silage can be more susceptible to oxygen ingress during storage (Forristal and O'Kiely 2005). In addition, damage to the plastic film surrounding bales occurs commonly on farms and permits direct ingress of air (McNamara *et al*. 2004; O'Brien *et al*. 2008); the impact of this is further accentuated by the greater surface-to-volume ratio and increased silage pore space in baled silage (Forristal and O'Kiely 2005). Upon such exposure of the silage to air, yeast, fungi and aerobic bacteria, which were dormant under anaerobic conditions, begin to flourish (Pahlow *et al*. 2003). It can be speculated that increasing the amount of stretch film applied to a bale should reduce the extent of fungal activity provided the integrity of the stretch film seal is maintained. Keles *et al*. (2009) recently reported that a minimum of 4 layers of stretch film were required to achieve suitably anaerobic conditions, and that the additional benefits of applying more layers were small. However, it is possible that the critical number of layers of stretch film required to adequately seal bales from air could increase where the duration of outdoor storage is extended by one season.

The objectives of the present study, undertaken at field-scale, were to investigate: (a) the impact of the number of layers of polyethylene stretch film on the conservation characteristics of baled silage, (b) the interactions between the number of layers of stretch film used and the duration of bale storage, and (c) the differences in conservation characteristics between baled and precision-chop silages. In addition, these comparisons each involved variation in the duration of wilting prior to ensiling.

Materials and Methods

Experimental design

Grass herbage was wilted for 0, 24 or 48 h and, in each case, representative samples were ensiled unchopped in bales (BS) or as precision-chop silage in clamp silos (PS). The bales were wrapped in 2, 4, 6 or 8 layers of black polyethylene stretch film and stored for 7 months, or were wrapped in 4, 6 or 8 layers of film and stored for 18 months. The precision-chop silage was stored for 7 months. Each treatment combination was replicated 6 times. Silage fermentation variables, in-silo fresh weight losses and indices of mould growth were assessed.

Harvest and ensiling

Herbages were produced and ensiled at Teagasc, Grange (53°31′N, 06°40′W). The 50-day regrowth of a permanent grassland sward (*Lolium perenne* dominant) was cut with a rotary mower-conditioner (Pottinger, Nova 310T conditioner mower) on 18 July and wilted for up to 48 h. There was little rainfall during harvesting (Table 1). After 0, 24 or 48 h of wilting, herbage was harvested from within representative replicate plots using a precision-chop harvester (Pottinger, Mex VI), or a round baler (Claas, 250 Rotacut Baler) with its chopping knives disengaged. After each wilting period, the bales (1.2 m wide by 1.2 m diameter; n = 42) were transported to their storage area, weighed, wrapped (McHale 991BE wrapper) with black polyethylene stretch film (standard 25 μm thick film to which a 1.70 stretch was applied; IP Europe, Gorey, Co. Wexford, Ireland) and stored outdoors, on their curved sides, on a bed of fine sand. Two layers of film were applied to 6 bales, and 4, 6 and 8 layers of film were each applied to 12 bales. Simultaneously, after 0, 24 and 48 h wilting, 6 separate samples of weighed precision-chop herbage were placed on polythene sheets, on a base of compacted sand, and sealed beneath 2 layers of black polythene sheeting (I.S. 246 1989; 0.125 mm thick) and fully covered with a layer of tyres. The mean (s.d.) fresh weight of the precision-chop herbage ensiled following 0, 24 and 48 h wilting was 4156 (295.2), 3548 (429.5) and 2970 (537.6) kg per clamp, respectively, while the corresponding values for mean weight per bale were 852 (54.3), 795 (84.6) and 581 (102.1) kg.

After each group (corresponding to each period of wilting) of 42 bales and the

Table 1. Mean daily weather conditions during harvesting and wilting

Date	Air temperature (°C)		Relative humidity	Sunshine (h)	Rainfall (mm)
	Minimum	Maximum			
18 July	12.4	18.5	0.88	4.3	0.2
19 July	8.0	18.0	0.85	3.1	0.0
20 July	9.2	20.0	0.80	5.3	1.2

herbage for 6 individual clamps had been removed from the field, the remaining herbage was tedded (Krone rotary tedder, model KW550/4x7) throughout the afternoon and windrowed (Krone 1471 windower, model KS380 420/12 Vario) in the late evening. All silages were protected from livestock and wildlife throughout the storage period (*ca.* 212 days (7 months) for 18 clamps and 72 bales, 556 days (18 months) for the remaining 54 bales).

Herbage pre-ensiling

A representative sample was taken from each clamp of precision-chop herbage and assessed for DM concentration by drying at 98 °C for 16 h in an oven with forced air circulation. All bales were core sampled (McEniry *et al*. 2006) and herbage DM concentration was determined as above. Replicate samples of precision-chop herbage were also dried at 40 °C for 48 h before being milled (Wiley mill) through a 1 mm screen. Dried, milled samples were used for determination of *in vitro* dry matter digestibility (DMD), ash, buffering capacity and crude protein (CP; total N x 6.25) as described previously (McEniry *et al*. 2006). The chemical composition of the pre-ensiled precision-chop herbage samples was assumed to be representative of the herbage ensiled in bales at the corresponding stage of wilting.

Herbage post-ensiling

The plastic film on each bale was assessed for damage immediately prior to bale opening, and the silage surface was then inspected for mould growth. The surface area of each visible colony was determined by placing a plastic grid (individual squares were 5 cm × 5 cm) over the colony and visually estimating its area. The percentage of the total surface area covered by fungal growth was then calculated for each bale. The silage in each bale or clamp was then weighed and a representative sample was taken for chemical analysis. The fresh weight loss was calculated as the difference between the herbage fresh weight ensiled and that removed from the silos, and expressed as a proportion of the fresh weight ensiled.

Silage samples were dried at 85 °C for 16 h in an oven with forced air circulation to estimate DM concentration, and corrected for the loss of volatiles by the equation of Porter and Murray (2001). Silage pH was determined from an aqueous extract using a pH electrode (Orion SA720 pH meter). Further juice was extracted for analysis of volatile fatty acids (VFA), lactic acid and ethanol, as previously described (McEniry *et al*. 2006), while the concentration of ammonia-N (NH_3-N) was determined using an enzymatic-UV kit (Thermo Electron Infinity Ammonia Liquid Stable reagent) on an Olympus AU400 (Olympus UK Ltd., Hertfordshire) clinical analyser.

Statistical analyses

Means and standard deviations (s.d.) were calculated for measurements of grass composition pre-ensiling. Other data were analysed using: (a) a two-way analysis of variance (baled silage after 3 durations of wilting (0, 24, 48 h) and wrapped with 2, 4, 6 or 8 layers of film, after 7 months storage), (b) a three-way analysis of variance (baled silage after 3 durations of wilting (0, 24, 48 h), wrapped with 4, 6 or 8 layers of film, and after 7 or 18 months storage), and (c) a two-way analysis of variance (baled silage (4 layers of stretch film) and precision-chop silage after 3 durations of wilting (0, 24, 48 h) and 7 months storage), using the GLM procedure of SAS (SAS 2004). This allowed an investigation of: (a) the impacts of number of layers of polyethylene stretch film on baled silage conservation characteristics, (b) the interactions between the number of layers of stretch film used and the duration of bale storage, and (c) the conservation characteristics of baled and precision-chop silages.

A detailed analysis of data on the proportion of bale surface visibly covered by mould, within a factorial structure, was inappropriate due to the non-normal distribution of the data. Transformations did not overcome this difficulty, so the individual treatment results are presented graphically.

Results

Herbage pre-ensiling

The mean (s.d.) DM concentration of the baled herbages after 0, 24 and 48 h wilting was 142 (6.9), 291 (28.6) and 533 (54.7) g/kg, respectively, which was similar to that observed for the corresponding precision-chop herbage pre-ensiling (Table 2). The buffering capacity was numerically higher for the unwilted compared with the wilted herbage, while wilting had little effect on *in vitro* DMD or on CP or ash concentrations.

Herbage post-ensiling

Wilting increased ($P<0.001$) lactic acid as a proportion of total fermentation products (especially the 24 h wilt treatment) and both the 24 and 48 h wilt treatments were equally effective in reducing ($P<0.001$) in-silo losses (Tables 3 to 5). Silage pH was highest ($P<0.001$) and lactic acid and total fermentation product concentrations were lowest ($P<0.001$) for the 48 h treatment. In general, the concentrations of acetic acid, ethanol and NH_3-N all declined ($P<0.001$) with increasing concentration of DM in the herbage, while propionic acid and butyric acid concentrations were highest ($P<0.001$) for the unwilted herbage.

Wrapping bales in only 2 layers of stretch film led to extensive visible mould growth on the bale surface (Figure 1). Visible mould growth was virtually eliminated by 4 or more layers of film, with the exception of the bales from unwilted herbage stored for 18 months (Figure 1); in the latter situation 6 layers of film were required to control mould growth. On average across wilt treatments, the use of 2 layers of stretch film was accompanied by an increase in silage pH ($P<0.001$) and NH_3-N concentration ($P<0.05$; Table 3). In addition, this treatment was associated with a decline in lactic acid ($P<0.05$; relative to bales wrapped in 6 or 8 layers of film), acetic acid ($P<0.05$; relative to bales wrapped in 8 layers of film), ethanol ($P<0.01$; relative to bales wrapped in 4 or 8 layers of film) and in the proportion of lactic acid in the fermentation products ($P<0.05$; relative to bales wrapped in 8 layers of film). Increasing the number of layers of stretch film from 2 to 4 led to a reduction ($P<0.001$) in silage pH and NH_3-N concentration, while there was a numerical increase in lactic

Table 2. Mean (s.d.) values for dry matter (DM) and chemical composition of herbage after wilting for 0, 24 or 48 h

Variable	Duration of wilting (h)		
	0	24	48
DM (g/kg)	145 (13.6)	296 (31.6)	530 (53.2)
In-vitro DM digestibility (g/kg)	724 (18.8)	729 (9.2)	733 (10.0)
Ash (g/kg DM)	124 (8.7)	125 (7.6)	116 (3.1)
Buffering capacity (mEq/kg DM)	616 (42.1)	484 (33.3)	500 (17.2)
Crude protein (g/kg DM)	147 (10.0)	142 (4.9)	136 (8.3)

Table 3. Effects of wilting and number of layers of polyethylene stretch film on fermentation variables (g/kg dry matter unless otherwise stated, except for pH) of baled silage, and on fresh weight loss after 7 months storage

Treatment		Variable†										
Wilt (h)	Layers of film	DM (g/kg)	pH	Lactic acid	Acetic acid	Propionic acid	Butryic acid	Ethanol	FP	L/FP (g/kg)	NH_3-N (g/kg N)	FWL (g/kg)
0	2	175	5.04	73	40.5	5.3	15.9	23.6	158	430	109	219
0	4	184	4.37	99	35.1	4.7	11.9	29.4	180	545	82	125
0	6	173	4.23	128	34.0	4.9	11.4	32.8	211	598	86	108
0	8	182	4.24	125	26.3	2.5	11.0	31.9	197	632	82	106
24	2	314	4.60	105	14.8	1.8	4.3	21.6	148	712	75	28
24	4	305	4.21	127	16.2	1.4	2.2	26.2	173	736	66	11
24	6	304	4.22	131	18.1	3.1	3.8	24.5	181	737	67	9
24	8	296	4.23	128	12.1	0.8	3.4	24.6	169	756	68	16
48	2	529	6.37	47	7.1	0.4	0.4	12.8	67	602	39	2
48	4	528	5.04	45	6.1	0.7	0.7	16.5	69	623	27	9
48	6	544	5.21	44	5.5	0.1	0.1	12.4	63	641	21	18
48	8	521	4.94	54	5.1	0.0	0.0	16.0	75	696	28	19
	s.e.	15.9	0.276	11.5	2.53	0.95	2.11	1.93	13.6	48.7	7.1	22.0
Significance												
Wilt		***	***	***	***	***	***	***	***	***	***	***
Layers of film			***	*	*			**		*	*	
Wilt x layers of film												

†DM = dry matter; FP = total fermentation products (lactic acid + acetic acid + propionic acid + butyric acid + ethanol); L/FP = proportion of lactic acid in fermentation products; NH_3-N = ammonia-N; FWL = fresh weight loss.

Table 4. Effects of wilting and duration of bale storage on fermentation variables (g/kg dry matter unless otherwise stated, except for pH) of baled silage, and on fresh weight loss (averaged across bales wrapped in 4, 6 and 8 layers of polyethylene stretch film)

Treatment		Variable†										
Wilt (h)	Storage (months)	DM (g/kg)	pH	Lactic acid	Acetic acid	Propionic acid	Butryic acid	Ethanol	FP	L/FP (g/kg)	NH_3-N (g/kg N)	FWL (g/kg)
0	7	180	4.28	117	31.8	4.1	11.4	31.6	196	592	83	113
0	18	163	4.66	74	32.3	5.4	11.7	20.1	143	520	110	163
24	7	302	4.22	129	15.4	1.8	3.1	25.1	174	743	67	12
24	18	293	4.24	76	11.1	0.5	1.3	20.2	109	696	59	17
48	7	531	5.06	48	5.5	0.3	0.3	14.9	69	653	25	15
48	18	539	4.90	51	4.2	0.1	0.0	8.4	64	713	19	14
	s.e.	9.4	0.075	6.2	1.50	0.56	1.33	1.07	7.0	27.7	3.66	4.2
Significance												
Wilt		***	***	***	***	***	***	***	***	***	***	***
Duration of storage				***				***	***			***
Wilt x duration of storage			**	***				*	***	*	***	***

†See footnote Table 3.

Table 5. Effects of wilting and ensiling system on silage fermentation variables (g/kg dry matter unless otherwise stated, except for pH), and fresh weight loss after 7 months' storage

Treatment		Variable[†]										
Wilt (h)	Ensiling system[‡]	DM (g/kg)	pH	Lactic acid	Acetic acid	Propionic acid	Butryic acid	Ethanol	FP	L/FP (g/kg)	NH_3-N (g/kg N)	FWL (g/kg)
0	BS	184	4.37	99	35.1	4.7	11.9	29.4	180	545	82	125
0	PS	154	4.45	99	50.9	8.7	6.0	24.6	189	587	79	132
24	BS	305	4.21	127	16.2	1.4	2.2	26.2	173	736	66	11
24	PS	292	4.42	104	20.1	2.9	2.3	19.1	149	804	54	21
48	BS	528	5.04	45	6.1	0.7	0.7	16.5	69	623	27	9
48	PS	475	5.28	76	6.5	0.9	0.7	6.3	91	909	67	121
	s.e.	13.4	0.095	9.8	3.06	1.13	0.95	1.47	10.0	38.6	6.3	20.0
Significance												
Wilt		***	***	***	***	***	***	***	***	***	***	***
Ensiling system		**	*		*		*	***		***		*
Wilt x ensiling system				*	*		**				***	*

[†]See footnote Table 3.
[‡]BS = baled silage (wrapped in 4 layers of polyethylene stretch film); PS = precision-chop silage.

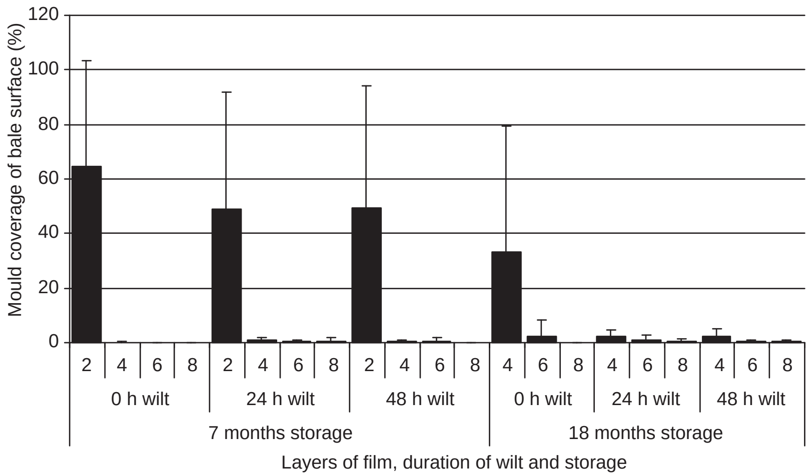

Figure 1. Mean (+ s.d.) percentage of surface area covered by mould for baled silage made after wilting herbage for 0, 24 or 48 h, wrapped in 2, 4, 6 or 8 layers of stretch film and stored for 7 or 18 months.

acid concentration. However, increasing the number of layers from 4 to 8 had no further impact ($P>0.05$) on the variables measured (Table 3).

On average, extending the storage period of baled silage from 7 to 18 months reduced the concentration of lactic acid, ethanol and total fermentation products ($P<0.001$), and increased in-silo losses ($P<0.001$) (Table 4). A numerical increase in surface mould growth was also observed (Figure 1). For the unwilted baled silage, extending the storage period increased silage pH ($P<0.01$) and NH_3-N ($P<0.001$) concentration. Prolonged storage reduced the concentrations of lactic acid ($P<0.001$) and total fermentation products ($P<0.001$) for the 0 h and 24 h wilt treatments and reduced ($P<0.05$) ethanol concentration for the 0, 24 and 48 h wilt treatments. Furthermore, the proportion of lactic acid in total fermentation products in the unwilted BS declined ($P<0.05$) with prolonged storage.

On average, across wilt treatments, the proportion of lactic acid in fermentation products was higher ($P<0.001$) and the ethanol concentration ($P<0.001$) was lower in the PS compared to BS (Table 5). Lactic acid concentration was lower ($P<0.05$) for the 48 h wilted BS, compared to PS, while no difference ($P>0.05$) was observed for the other wilt treatments. On average, acetic acid concentration was higher ($P<0.05$) and butyric acid concentration lower ($P<0.05$) for PS than BS, and this was particularly evident for the unwilted silages. The NH_3-N concentration in PS after the 48 h wilt was more than double ($P<0.001$) that for the corresponding BS treatment. In addition, in-silo losses were higher ($P<0.05$) for PS after 48 h wilt than the corresponding BS, while for the other wilt treatments the differences between the ensiling systems were negligible.

Discussion

Herbage pre-ensiling

Field wilting of herbage is often difficult under Irish weather conditions. However, in the current experiment, herbage DM concentration had reached 296 and 530 g/kg after 24 and 48 h wilt, respectively. The mean hourly drying rates during these sequential 24 h periods were 6.3 and 9.8 g/kg, respectively; good drying conditions by local standards.

The high DMD (724 g/kg) and CP (147 g/kg DM) concentration observed for the unwilted herbage at harvest indicate a relatively young leafy crop. The ash concentration for all herbages (122 g/kg DM) was slightly above normal (<100 g/kg DM according to McDonald, Henderson and Heron 1991), and likely reflects some level of soil contamination either on the standing crop or during mowing or harvesting. The reduction in buffering capacity over the first 24 h of wilting agrees with the general findings of O'Kiely *et al*. (2005) and may be partly explained by respiration of plant organic acids.

Herbage post-ensiling

In general, pH and the concentration of fermentation products were indicative of a satisfactory preservation for all treatments except for the unwilted BS covered with 2 layers of stretch film, based on the preservation index thresholds described by Haigh and Parker (1985).

Wilting

As the duration of wilting, and thus as the DM concentration, of the herbage increased the subsequent silage fermentation became more restricted. This resulted in a lower concentration of fermentation products and, in general, a higher pH in the wilted silages in accord with McEniry *et al*. (2008) and Keles *et al*. (2009). These effects are explained by the lower water activity of the wilted herbage (0.966, 0.987 and 0.995 for the 48, 24 and 0 h wilting periods, respectively; Greenhill 1964), which would have created more inhibitory conditions for microbial fermentation (Woolford 1984).

Besides silage from unwilted herbage being more extensively fermented (i.e., higher concentration of fermentation products), it was also less well preserved than the silages from wilted herbage, as indicated by a lower proportion of lactic acid in fermentation products and a higher proportion of NH_3-N in total-N. The higher proportion of lactic acid in fermentation products observed for silages made from wilted herbage indicates the dominance of lactic acid bacteria, especially homofermentative lactic acid bacteria, during ensiling. In addition, increasing the duration of wilting reduced the concentration of NH_3-N in the silage, indicating a considerable curtailment of proteolysis. In contrast, the high pH, and the relatively high concentrations of NH_3-N and butyric acid, observed for some unwilted silages are indicative of undesirable clostridial activity. However, the reduction in the concentration of the latter fermentation products with wilting demonstrates the inhibitory effects of both a lactic acid dominant fermentation and a high herbage DM concentration (i.e., reduced water activity) on *Clostridia*, as previously reported by Wieringa (1958).

Although not recorded, the low DM concentration of the unwilted material would have resulted in effluent production, and this likely contributed to the high in-silo fresh weight losses reported for silages from unwilted herbage. Effluent is generally produced if the DM concentration of the crop to be ensiled is below 300 g/kg, although this threshold for effluent output is highly dependent on the level of compaction or pressure exerted on the crop (Lenehan, O'Kiely and Forristal 1997; Weinberg and Ashbell 2003). In contrast, in-silo losses remained low (< 30 g/kg) for the wilted silages. In addition to effluent production, it is possible that losses associated with increased mould growth on some of the unwilted baled silage contributed to their higher in-silo losses.

Layers of stretch film

Standard bale wrapping procedures in Ireland require the application of at least 4 layers of stretch film to meet requirements for impermeability to oxygen (Forristal and O'Kiely 2005). When bales are stored under good conditions, where a low pH and anaerobic conditions prevail, mould growth should be greatly reduced or prevented (Keles *et al*. 2009). Unfortunately, damage to the stretch film surrounding bales appears to be a common occurrence on farms (McNamara *et al*. 2004), with O'Brien *et al*. (2008) reporting that fungal colonies were visible on 92% of the bales examined during an investigation into the incidence of mould growth on baled grass silage in Ireland. In the current experiment, mould cover was unacceptably high for the baled silage wrapped with only 2 layers of stretch film. This is in agreement with Keles *et al*. (2009) and indicates that there was excessive ingress of air into the bales during storage. The shrinkage of the herbage mass due to plant cell lysis and effluent loss (for the unwilted herbage), and the resulting loss of bale shape, may also have resulted in the disruption of the integrity of the seal between the layers of film (Hancock and Collins 2006), thereby facilitating the air ingress.

Although some lactic acid was present when only 2 layers of stretch film were applied to baled silage, this amount of film did not create sufficiently anaerobic conditions to allow a lactic acid fermentation to dominate. After wrapping, the oxygen trapped within the bale should be utilised within a few hours by the herbage and its epiphytic microflora, and the production of carbon dioxide as a product of this respiration means that net gas movement during the early stages of ensilage is likely to be outward past the stretch film. Even where only 2 layers of stretch film have been applied, conditions within the bale should be relatively anaerobic in the early stages of ensiling (Keles *et al*. 2009). However, once net gas outflow ceases, any ingress of oxygen into a bale can disrupt the primary fermentation, promoting the activities of aerobic bacteria, yeast and mould, and can facilitate a secondary fermentation (Pahlow *et al*. 2003). Thus, for example, the high pH and NH_3-N values indicate that more extensive clostridial activity occurred when only 2 layers of stretch film were used, and the corresponding lower concentration of lactic acid suggests that lactic acid may have been an important substrate for this process (Jonsson 1991). Overall, the inferior standard of silage preservation, the high in-silo losses of the ensiled herbage and the extent of visible mould growth are indicative of a marked failure of conservation when bales were wrapped with only 2 layers of conventional stretch film.

Increasing the number of film layers applied from 2 to 4 had a dramatic beneficial effect on most indices of conservation. The reduction in silage pH and the numerical increase in the concentration of fermentation products, especially lactic acid, is indicative of the creation of more anaerobic conditions, and of the dominance of a lactic-acid fermentation and the curtailment of undesirable anaerobic microbial activity. This was further reflected in the reduction in visible mould growth on bales stored for 7 months. Forristal, O'Kiely and Lenehan (1999) reported similar findings for baled silage, with the extent of the visible mould growth area on the bale surface declining progressively from 21.5 to 1.7 to 0.7 % for bales covered with 2, 4 and 6 layers of film, respectively. Similarly, Heikkila *et al*. (2002) found less mould growth with 6 than with 4 layers of film. A further increase in the number of layers of film from 4 to 6 or 8 had little effect on the other variables measured in the present experiment and this is in agreement with Keles *et al*. (2009).

Duration of bale storage

Prolonged bale storage (18 compared to 7 months) had a negative impact on the composition of unwilted baled silage and resulted in substantial loss of fermentation product and an increase in visible mould growth. This increase in mould growth is indicative of air ingress during storage and, as stated above, would have facilitated the reactivation of aerobic microorganisms causing spoilage (McDonald *et al*. 1991). This was further reflected in the lower concentration of fermentation products and higher in-silo losses. The increase in mould growth was particularly evident for unwilted baled silage covered with 4 layers of film, indicating that the application of 6 layers of film should be standard practice for prolonged storage of baled silage from unwilted herbage, under Irish conditions.

Ensiling system

The chemical and microbiological composition of BS frequently differs from that of comparable conventional PS. McEniry *et al*. (2006) reported average values for pH, lactic acid, acetic acid and butyric acid of 4.55 and 3.85, 42 and 103 g/kg DM, 15 and 43 g/kg DM, and 10.4 and 6.2 g/kg DM, for baled and precision-chop silages (no silage additives applied) on Irish farms, respectively. However, large differences in DM concentration between these silages were also reported; the mean (s.d.) DM concentration of the baled silage (360 (120) g/kg) indicating that wilting was an integral part of baled silage production whereas the conventional silage was generally ensiled with a modest or no effective wilt (DM = 220 (24.5) g/kg).

Some small differences were observed between the two ensiling systems in the current experiment. The high concentration of lactic acid in both the unwilted and 24 h wilted BS and PS suggests a relatively extensive fermentation, resulting in a similarly low pH. Furthermore, the lactic acid concentration was higher and silage pH lower (24 h wilted BS) than values reported by McEniry *et al*. (2006) for baled silage on farms, and is indicative of a more extensive fermentation under better management conditions. The reduced presence of fungal inhibitors, such as acetic and propionic acids, in BS may have contributed to the increased incidence of mould growth on the bale surface (Danner *et al*. 2003).

However, in general BS, when wrapped in 4 layers of stretch film, did not differ greatly from PS in the extent or overall direction of fermentation or in in-silo losses. As herbage DM concentration increased with increasing duration of wilting, the fermentation of both the BS and PS became similarly more restricted. For both ensiling systems the unwilted silage underwent the most extensive fermentation but these silages were less well preserved. In contrast, the higher proportion of lactic acid in fermentation products observed for the wilted silages in both systems indicates a dominant homofermentative lactic acid bacterial fermentation.

Conclusions

Wrapping bales in only 2 layers of stretch film failed to create the anaerobic conditions required for a successful fermentation and the inhibition of visible fungal growth. While 4 layers of conventional stretch film are normally sufficient, 6 layers should be applied when prolonged storage of unwilted baled silage is required under Irish conditions. When baled silage was wrapped in 4 layers of polyethylene stretch film and stored for 7 months the chemical characteristics and in-silo losses generally did not differ from those of comparable precision-chop silage. Differences observed between baled and precision-chop silages under good farm-management conditions are therefore probably mainly the result of differences in herbage DM concentration. Under poor management conditions, the differences are likely to be a result of air infiltration into the bales in combination with differences in DM concentration.

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